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Leaf Diffusive Resistance and Relative Water Content as indications of Varietal Sensitivity to Drought in Potatoes

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ABSTRACT

Stressed plants of both the 'Katahdin' and 'Superior' varieties exhibited an increase in leaf diffusive resistance and a slight decrease in relative water content. There were minor varietal differences in relative water content of stressed plants but the pattern of change in leaf water content was similar in both varieties. There were, however, significant varietal differences in the pattern of leaf diffusive resistance responses to water stress. Although unstressed plants of both varieties had nearly identical leaf diffusive resistance values, stressed 'Superior' displayed higher leaf diffusive resistance than 'Katahdin' under the same conditions of environmental stress.

INTRODUCTION

Variety trials are conducted to evaluate the performance of potato (Solanum tuberosum L.) varieties under regional environmental conditions. Since northeastern states frequently experience drought, a method of screening varieties for responses to water deficit, prior to field trials, would be a valuable tool in determining the suitability of a variety for the area.

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The objective of this study was to examine the physiological responses of 'Katahdin' and 'Superior' potato varieties subjected to moisture stress early in the plant growth cycle and to relate any immediate plant response to stress to the final yield of plants grown to maturity. Physiological responses measured under controlled conditions were leaf relative water content and leaf diffusive resistance. These processes were measured on stressed and unstressed plants of both varieties during a 10 day cyclic stress/non-stress period. Subsequent to the stress cycle, half of the plants were harvested and haulm production and tuber yield were measured. The remaining half of the plants were grown to maturity with optimal water supply and harvested.

METHODS AND MATERIALS

Plant material: Two potato (Solanum tuberosum L.) varieties were grown in containers and subjected to water stress in the Plant Science Greenhouse Research Facility, Storrs, CT. Whole tubers, weighing approximately 60 g each, were green sprouted in indirect light for 2 weeks prior to planting to encourage sprout development and reduce the time necessary for shoot emergence from the soil. Sixteen uniformly sprouted tubers of each variety were treated with captan and planted, one per pot, at a depth of 6 cm in 8 l plastic containers. The growing medium was a sand/soil/peat (ratio 1:2:1) mixture with a pH of 6.0.

Pots were kept moist with tap water prior to sprout emergence. Following emergence, plants received liquid fertilizer, 15-30-15 (2.2 g/l) twice weekly for 2 weeks, and 20-20-20 (2.2 g/l) twice weekly thereafter throughout the experiment. Routine greenhouse spraying was performed to control insect pests.

The daylength average was 12 hours of natural light for the duration of the experiment, which extended from March to

July. Daytime temperature fluctuated with the ambient weather conditions. Night temperature was 10 C minimum. Treatments were arranged in a completely randomized design with 4 replications per harvest date. Treatments consisted of the variety and water stress.

Drying cycle: Eight plants of each variety were subjected to water stress by withholding water at the time of tuber initiation. This was assumed to begin at blossoming. All stressed plants were allowed to wilt between water applications for a period of 10 days, resulting in a cyclic stress/non-stress water regime. Control plants were watered daily during this period but received no fertilizer. Stressed plants received water twice in 10 days, when vines were flaccid.

Leaf diffusive resistance measurements: Leaf diffusive resistance was measured daily during the 10 day stress cycle with an aspirated diffusion porometer (Turner, Pederson and Wright, 1969). Measurements were taken on the abaxial surface of fully expanded terminal leaflets at the fifth node of six plants from each treatment. Porometer readings were taken at the same time each day, between 9 and 10 a.m., to eliminate the variability in readings resulting from diurnal changes in stomatal activity. Values for leaf diffusive resistance are in the form of time (seconds) necessary to produce a standard change in electrical resistance in a resistor. Changes in resistance are a result of the absorption of water vapor from the leaf surface. The time involved is directly related to the rate of diffusion of water vapor from the leaf surface. Increase in the time necessary for a change in resistance indicates increased leaf resistance. Diffusion porometers measure total leaf resistance, i.e. stomatal and cuticular resistance. It is assumed, however, that cuticular water loss is small and changes in resistance are due to changes in stomatal aperture (Sanchez-Diaz and Kramer, 1971).

Relative water content determinations: Relative water content was measured daily during the stress cycle by the method of Barrs and Wetherley (1962). Three plants from each treatment were sampled randomly each morning between 10 and 11 a.m. Leaf discs 1 cm in diameter were removed with a cork borer from the terminal leaflet of the 6th to the 8th leaf from the main shoot apex. Discs were wrapped in plastic and placed in petri dishes, transported immediately to the laboratory adjacent to the greenhouse and weighed. Discs were then floated in distilled water in covered petri dishes at a light intensity of 65 f.c. and a constant temperature of 22 C. After 4 hours, discs were removed, blotted dry and re-weighed. Dry weights were obtained after oven-drying discs for 24 hours at 80 C. The relative water content (RWC) of the leaf tissue was calculated by:

$$RWC = \frac{\text{Fresh weight} - \text{dry weight}}{\text{Turgid weight} - \text{dry weight}} \times 100$$

This calculation of relative turgidity is based on a comparison of the initial fresh weight of the plant tissue and the fully turgid weight obtained after the flotation period. Water uptake can be divided into two phases. Phase I is the rapid initial uptake following water deficit and Phase II is the slow steadystate uptake resulting from plant growth. Limiting the flotation period to 4 hours and maintaining the light intensity at 65 f.c. eliminates Phase II uptake as a factor in RWC calculations. Dry weights of leaf discs are constant as the flotation environment maintains the CO_2 compensation point so that no weight gain or loss occurs.

Post-stress and mature harvests: At the end of the 10 day stress cycle, half of the plants, 4 stressed and 4 unstressed of each variety, were harvested. The remaining plants were grown to maturity under optimal water supply and harvested.

At both the post-stress and mature harvests, plant tops were severed at the soil line and oven-dried at 80 C. Tubers were weighed and counted. Statistical analysis of all harvest data and physiological measurements of stressed and unstressed plants of the same variety was performed using the paired t test.

RESULTS

Yield data: Differences between stressed and control haulm dry weights were significant at the 5% level in both varieties at the post-stress harvest. However, persistent reductions in vine production were not evident at the mature harvest in either variety (Table 1).

The trend was toward a reduction in total tuber yield/plant in stressed plants in both harvests of both varieties, although the reductions were not significant (Table 2). The reductions in tuber production were more marked at the mature harvest than at the post-stress harvest.

Relative water content: RWC values were lowest in stressed plants of both varieties on days when plants were extremely wilted and measurements were taken just prior to rewatering (Fig. 1). An initial decrease in RWC in stressed plants occurred in both varieties at the beginning of the drying cycle. Following the first rewatering, RWC of stressed plants was greater than the control value in both varieties. No such pattern was evident after the second rewatering. Control values remained relatively constant over the 10 day period. No significant decreases in RWC were evident in stressed plants of either variety during the entire drying cycle. Similarly, Epstein and Grant (1973) reported finding no varietal differences in RWC in stressed potato leaves.

Table 1. Haulm dry weights for varieties 'Superior' and 'Katahdin' grown to maturity in the greenhouse.

Variety	Treatment	Post-stress Harvest[+] g/plant	Mature Harvest[+] g/plant
Superior	Control	27.4	13.8
Superior	Stress	15.8*	13.9
Katahdin	Control	33.9	23.3
Katahdin	Stress	18.2*	18.8

[+]All values represent mean of four replications.

*Significantly different from control of the same variety at the 5% level.

Table 2. Tuber yields for varieties 'Superior' and 'Katahdin' grown to maturity in greenhouse.

Varieti	Treatment	Post-stress Harvest[+]		Mature Harvest[+]	
		#/plant	g/plant	#/plant	g/plant
Superior	Control	9	328.5	9	651.3
Superior	Stress	8	293.9	8	560.5
Katahdin	Control	7	198.0	8	578.8
Katahdin	Stress	10	195.1	8	493.9

[+]All values represent mean of four replications.

Leaf diffusive resistance: Significant differences between control and stress values for leaf diffusive resistance were evident in both varieties at various points throughout the drying cycle (Fig. 2). The control values for resistance were relatively constant at a mean 11.72 seconds and 9.85 seconds for 'Katahdin' and 'Superior' respectively. Stressed plants of both varieties exhibited a similar pattern of resistance fluctuation with changes in water supply. However, stressed 'Superior' displayed a greater resistance on days of minimum water supply than did 'Katahdin'. Following the first rewatering, there is also an apparent differential varietal response: stressed 'Superior' leaves exhibit lower resistance than 'Superior' control plants, whereas stressed 'Katahdin' leaves exhibit greater resistance than control leaves following rewatering.

DISCUSSION

Water deficits result in stomatal closure indicated by increased leaf diffusive resistance. Photosynthesis decreases in potato leaves as resistance increases (Moorby, Munns, and Walcott, 1975) and stomatal aperture decreases (El-Sharkaway and Hesketh, 1964). This reduction in photosynthesis is largely a result of the effect of increased resistance to gas exchange with closing stomates, resulting in limited CO_2 entry into the mesophyll (Mederski, Chen, and Curry, 1975).

Following a stress period, physiological processes in leaves may also be altered. Photosynthetic rate does not always recover immediately following stress relief (Boyer, 1971) and can take several days to recover fully, depending on the length and severity of the stress (Ashton, 1956; Bielorai and Hopmans, 1975). In cyclic stress situations photosynthesis fails to recover fully after each successive drought (Todd and Webster, 1965).

Because of the relationship between stomatal action and basic metabolism, the pattern of stomatal response under stress may be an important factor in a species' sensitivity to water deficits. Drought resistance in certain crop species has been related to stomatal function under stress. Turner (1974) postulated that the greater yielding ability of sorghum than corn under conditions of water deficits may result from the ability of sorghum to maintain stomatal aperture at lower water potentials than corn. This would result in greater water loss but would also allow photosynthesis to continue. Rutherford and DeJager (1975) have developed a method for quantitatively predicting yield reductions in BP_1 potatoes based on stress symptoms including leaf diffusive resistance. They established that leaf diffusive resistance of 5 s cm^{-1} (or a value of 1.5 x normal values) will result in yield reductions of 0.24%/stress hour or 3.7%/stress day. Thus, the magnitude of the yield reduction in response to water stress is dependent on a time factor and the longer stomatal aperture is reduced, the greater the yield reduction.

Results of this study indicate that 'Superior' developed greater resistance under stress than 'Katahdin'. 'Superior' has been observed to perform poorly under conditions of water stress (Ashley, 1979) with both yield and quality being reduced. In this study, a direct correlation between stomatal response and yield is not possible. However, the already established relationship between stomatal action and yield in BP_1 potatoes (Rutherford and DeJager), the relationship between drought resistance and stomatal response in other crop plants, and the observed varietal differences in potato leaf diffusive resistance under conditions of water stress would seem to hold promise for development of a screening method for potato varietal sensitivity to drought based on stomatal response to stress.

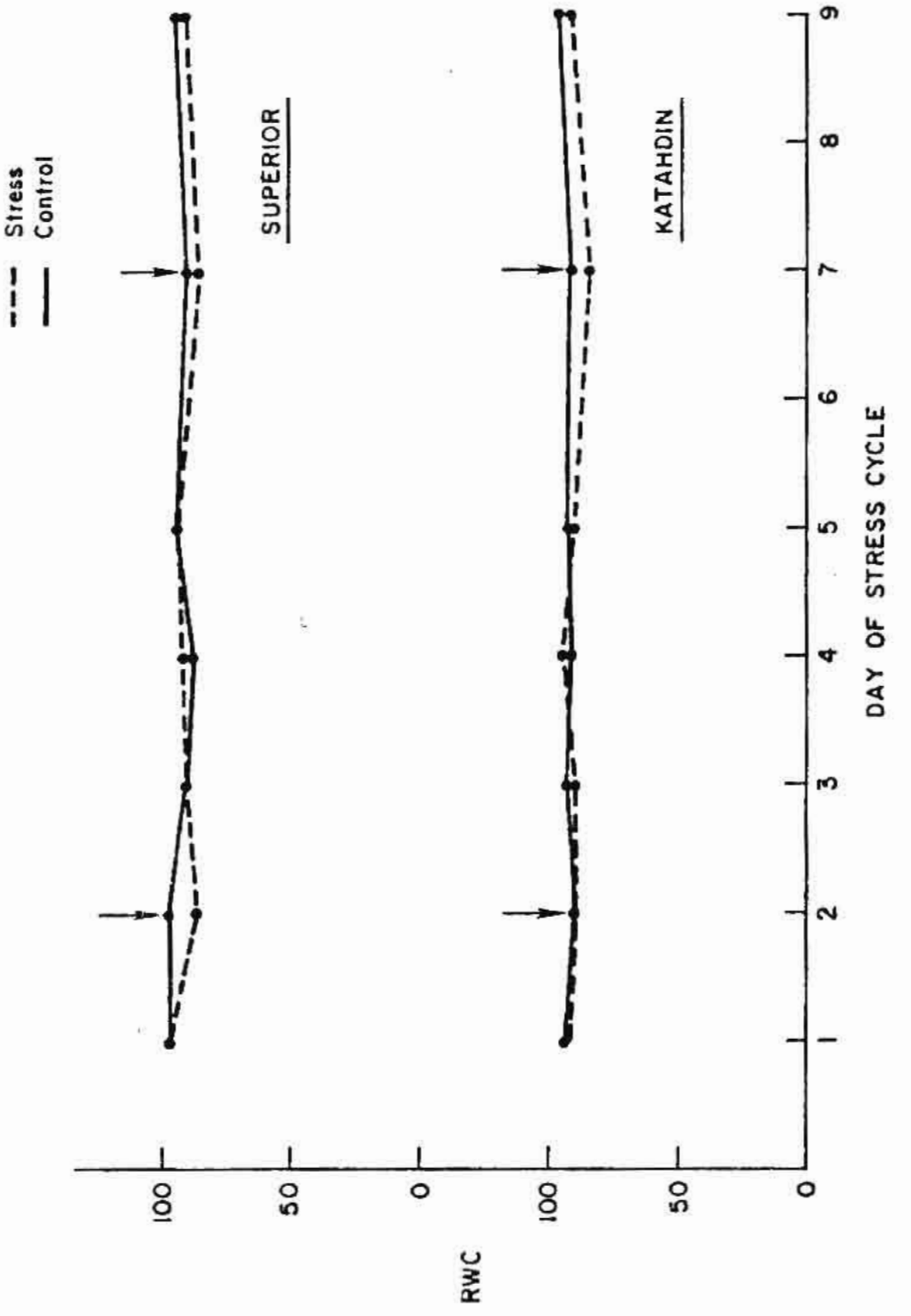

Figure 1. Relative water content (RWC) of varieties 'Superior' and 'Katahdin' during cyclic stress/non-stress period. Arrows indicate rewatering of plants.

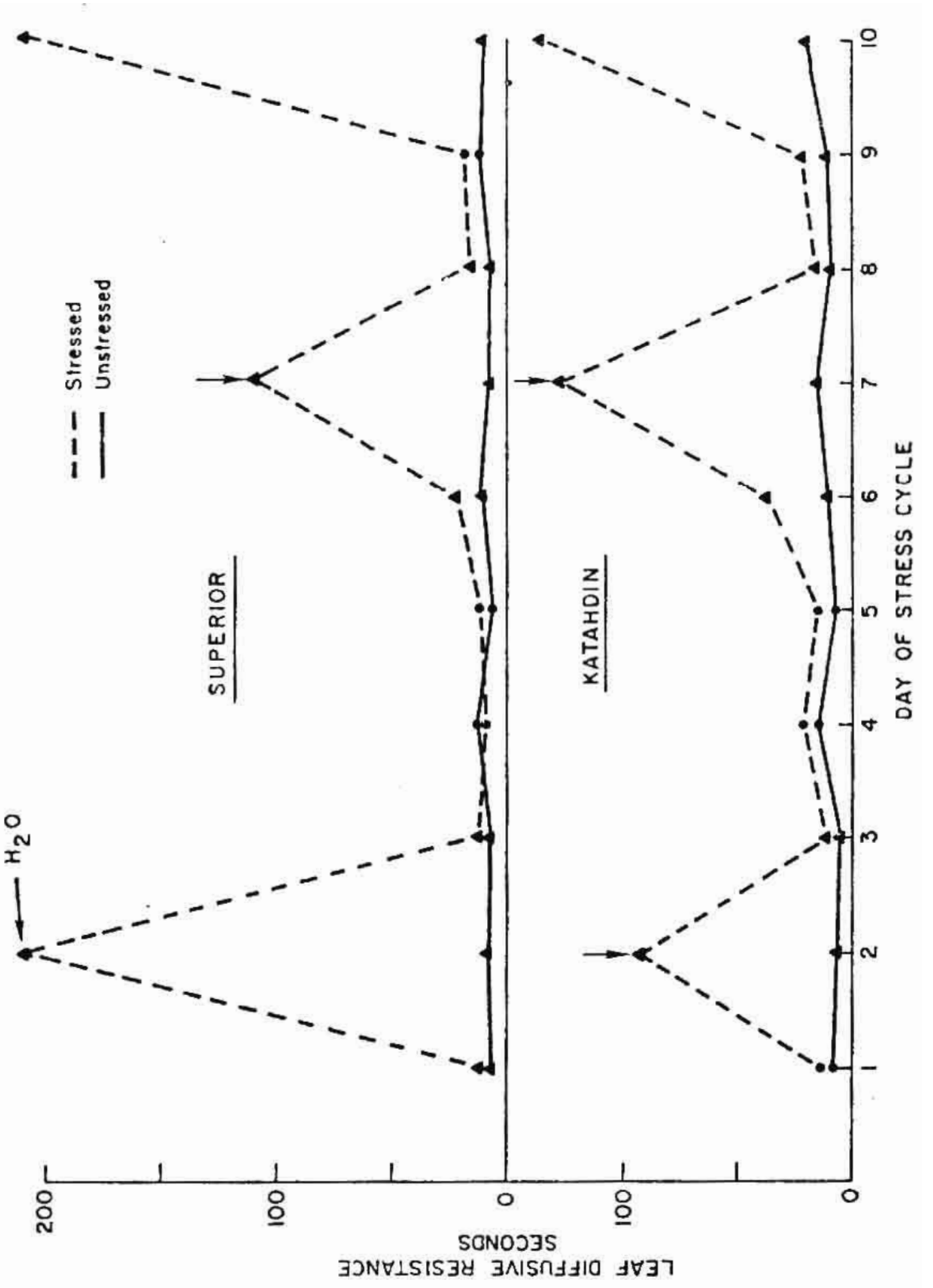

Figure 2. Leaf diffusive resistance in varieties 'Superior' and 'Katahdin' during a 10 day cyclic moisture stress/nonstress period. Arrows indicate rewatering of stressed plants. Points marked by (▲) on the same day for stressed and unstressed plants are statistically different at 5% level.

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